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GB 2224156 A EP 0408963 A2 US 4930040 A
US 4823825 A US 4653447 A

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(54) **Method of and equipment for determining a control parameter for an electromagnetic device**

(57) A method of determining a control parameter for control of an electromagnetic load 100 incorporating a movable element (e.g. a fuel injection valve of an i.c. engine) comprises the step of ascertaining a switching instant (T_{BIP}) at which the movable element reaches an end position (X2) by detection of a discontinuity in the temporal course of a magnitude which corresponds to the current (I_M) through the electromagnetic load, the switching instant being ascertained during a freewheel phase. The stroke of the movable element is shown by a chain-dotted line, the current by a dashed line in Fig. 2b. In the freewheel phase, switch 110 is open and the load (coil) current flows through diode 150 and current sensor 145. A time window T2 - T3, within which the switching instant is expected, is set in dependance on engine operating conditions.

FIG. 1

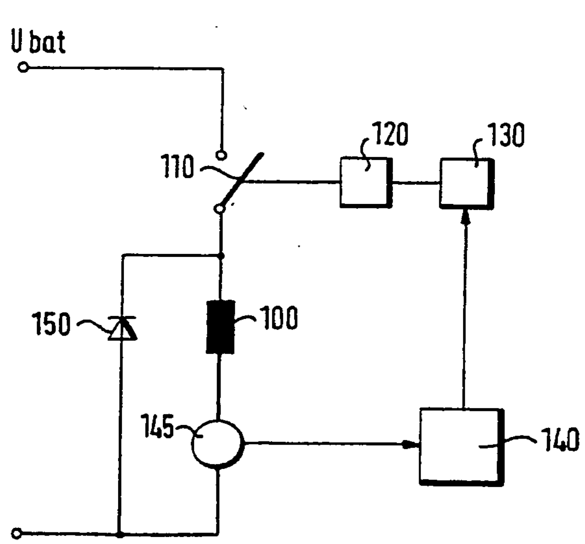

FIG. 2b

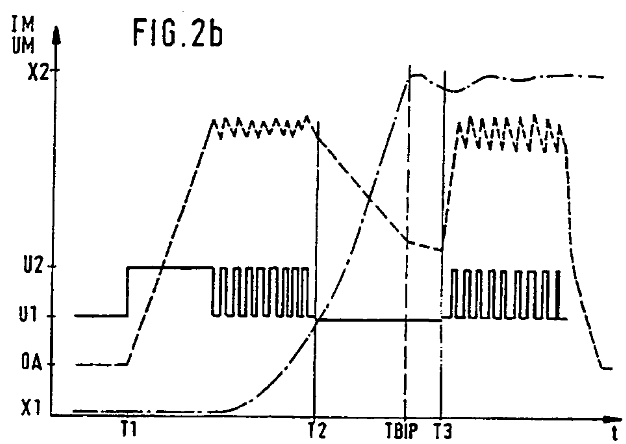

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FIG. 1

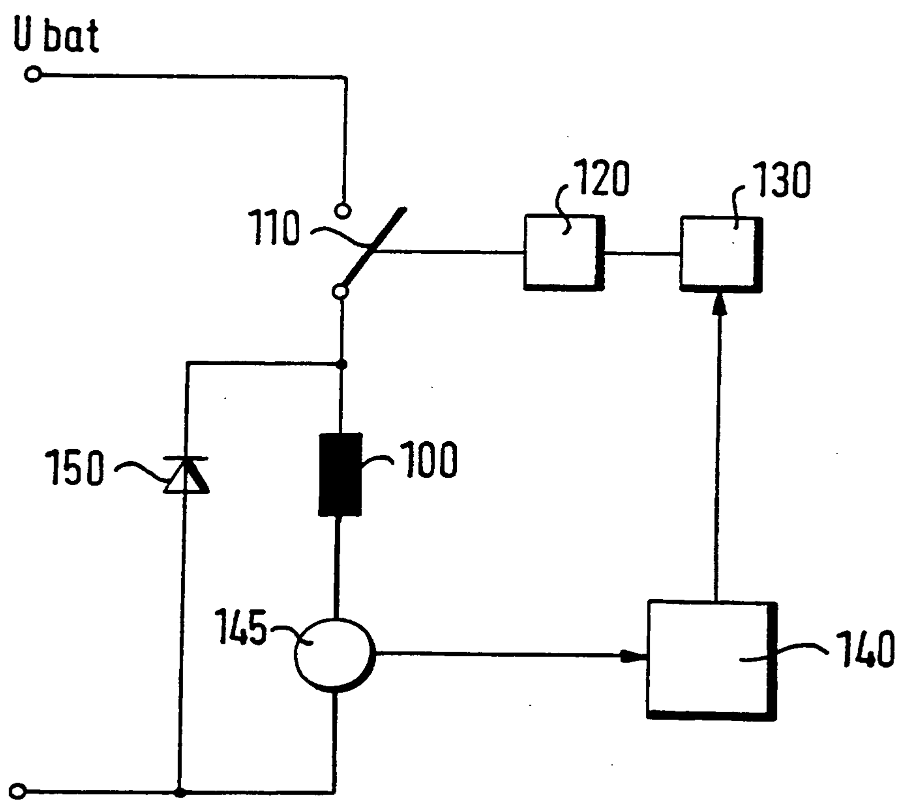
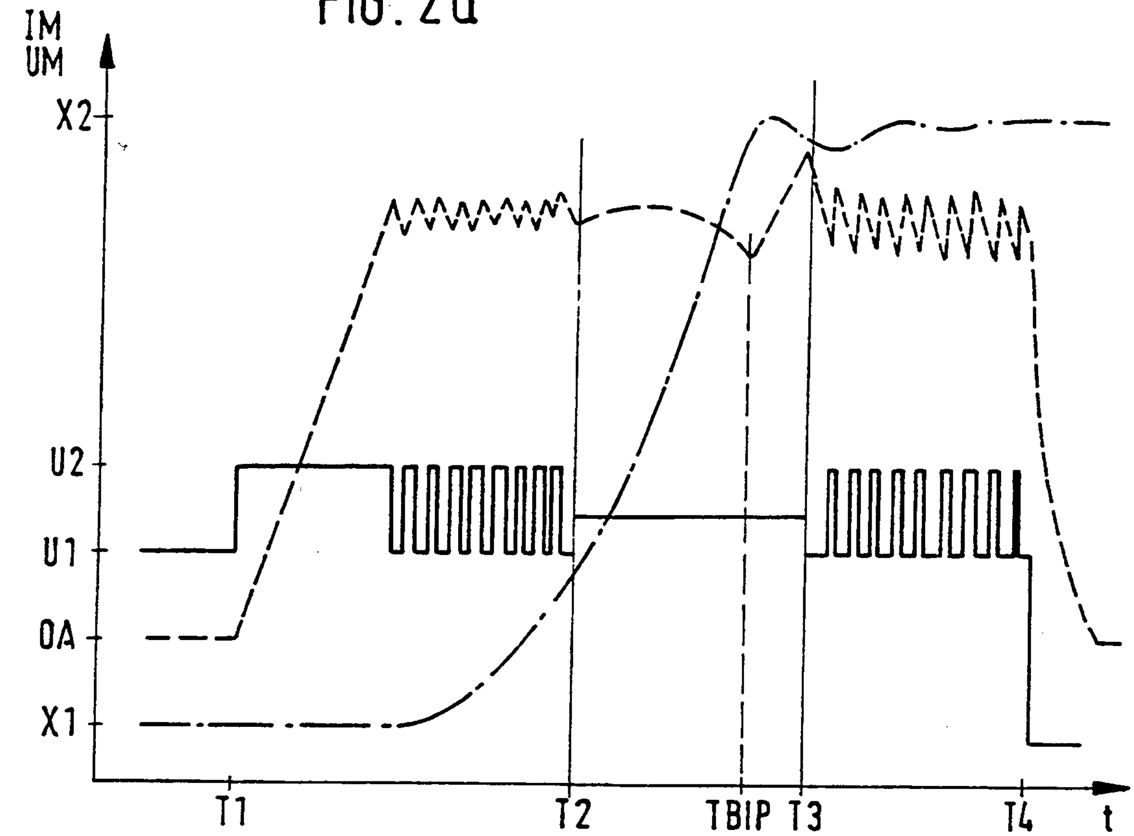


FIG. 2a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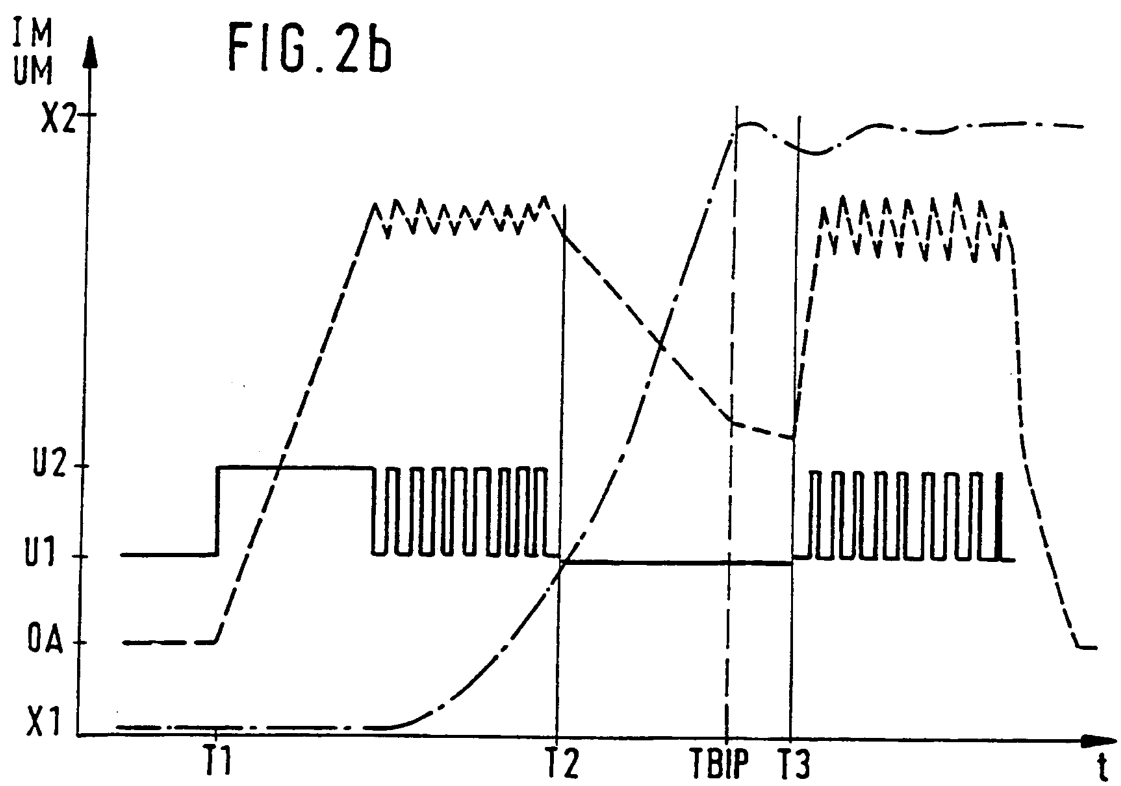
UM
X2
U2
U1
0A
X1
T1
T2
TBIP
T3
T4
t

FIG. 2b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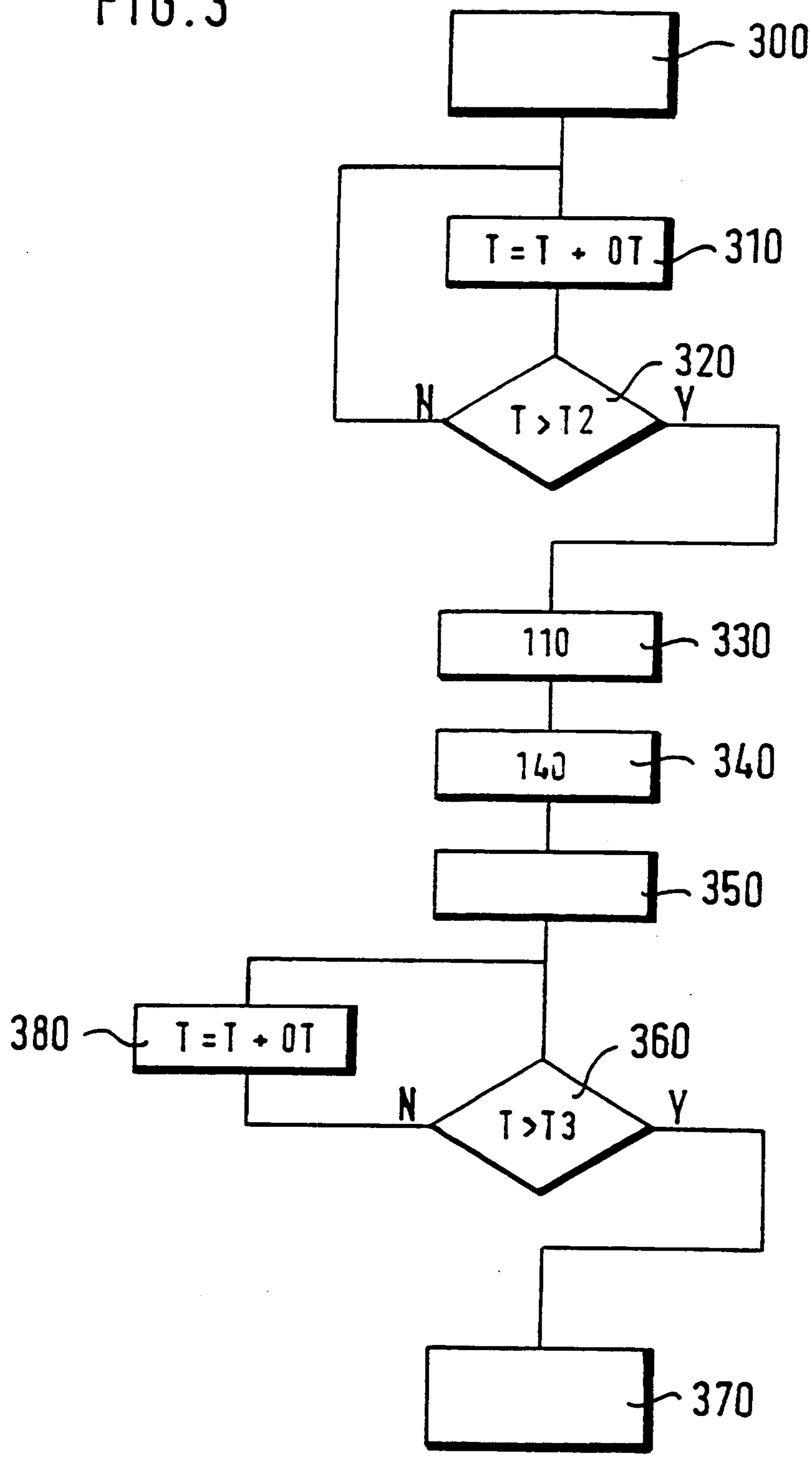
UM
X2
U2
U1
0A
X1
T1
T2
TBIP
T3
t

FIG.3


300
T = T + ΔT
310
320
N
T > T2
Y
110
330
140
340
350
380
T = T + ΔT
360
N
T > T3
Y
370

METHOD OF AND EQUIPMENT FOR DETERMINING A CONTROL PARAMETER FOR AN ELECTROMAGNETIC DEVICE

The present invention relates to a method of and equipment for determining a control parameter for an electromagnetic device.

A method and equipment for drive control of an electromagnetic valve is known from DE-OS 34 26 799 (US-A 4 653 447). The switching instants and, starting therefrom, the switch-on and switch-off times of the valve are detected by the described equipment. Starting from the temporal course of the current through the valve, the exact switching instant of the valve is determined.

Such electromagnetic valves are used for, for example, control of the injection of fuel into petrol and/or diesel engines. For the exact admetering of even very small injected quantities, the switching instant at which the armature of the current-carrying valve reaches one of its two end positions is a point of reference. In known control systems, the current course is evaluated in a time window within which the switching instant usually occurs and the switching instant is determined by reference to its temporal course.

There remains scope for simplified or more accurate determination of the switching instant for use in drive control of an electromagnetic load.

According to a first aspect of the present invention there is provided a method of determining a control parameter for an electromagnetic device incorporating a movable element, the method

comprising the step of ascertaining a switching instant at which the movable element reaches an end position during movement thereof by detection of a discontinuity in the temporal course of a magnitude corresponding to the current through the electromagnetic device, the step of ascertaining being carried out during a freewheel phase.

According to a second aspect of the invention there is provided equipment for determining a control parameter for an electromagnetic device incorporating a movable element, comprising means to ascertain during a freewheel phase, a switching instant at which the movable element reaches an end position during movement thereof by detection of a discontinuity in the temporal course of a magnitude corresponding to the current through the electromagnetic device.

Due to the switching instant being ascertained during a freewheel phase, there is no requirement to regulate the voltage during the time window. At the same time, the expended loss power is reduced significantly by comparison with equipment incorporating voltage regulation.

An examkple of the method and embodiment of the equipment of the invention will now be more particularly described with reference to the accompanying drawings, in which:

Fig. 1 is a schematic block diagram of an electromagnetic load and associated control circuit;

Fig. 2a is a diagram illustrating signal courses in a method not exemplifying the invention;

Fig. 2b is a diagram illustrating signal courses in a method exemplifying the invention; and

Fig. 3 is a flow chart illustrating steps in a method exemplifying the invention;

Referring now to the drawings there is shown in Fig. 1 equipment for the switching of an electromagnetic load. In principle, the equipment is usable in conjunction with any electromagnetic load, thus not restricted to a specific application. It is, however, particularly suitable for use in the context of engine management, especially in connection with admetering of fuel into a combustion chamber of an internal combustion engine. An electromagnetic valve, representing the load, can be employed for the control of the admetering fuel.

In that case, it is necessary, in particular for small loads, to admeter small injected quantities as accurately as possible. This in turn requires knowledge of the instant at which the armature of the current-carrying electromagnetic valve reaches an end position. This instant is usually denoted as beginning of injection period (BIP) and is ascertained by evaluation of the temporal course of the valve current. In particular, the temporal course of the current at constant voltage or the temporal course of the voltage at constant current can be evaluated to determine whether this course has a discontinuity or a significant change in the difference quotient of the magnitude under consideration.

Fig. 1 shows the principal elements of equipment for control of an electromagnetic valve which controls fuel admetering equipment. An electromagnetic load 100, i.e. the valve, is connected at one terminal with voltage supply equipment Ubat by way of a switch 110. The switch 110 is driven by a drive control device 120. The device 120 is in turn connected with a current regulator or voltage regulator 130.

The other terminal of the electromagnetic load is connected with ground by way of a sensor 145. The sensor 145 is connected with an evaluating device 140, which is connected with the voltage regulator or current regulator 130. A freewheel device 150 is connected in parallel with the series connection of electromagnetic load 100 and sensor 145. In the simplest embodiment, the freewheel device 150 consists of an appropriately connected diode.

The sequence of the components in the series connection of the switch 110, load 100 and sensor 105 can be different if so desired. It is important only that the sensor 145 is electrically connected directly with the load even when the switch 110 is opened and the current flowing in the freewheel phase or the voltage present can be measured by the sensor 145.

The mode of operation of this equipment is described in the following by reference to Figs. 2a and 2b, in which the stroke H of the valve needle is represented by a chain-dotted line, the voltage U_M across the valve by a solid line and the current I_M flowing through the valve by a dashed line. These signal courses are entered as a function of time t.

The signal courses in the case of equipment with voltage regulation are illustrated in Fig. 2a. The illustration is only by way of example, and the actual temporal courses very much depend on the type of electromagnetic valve used and on the voltage that is present.

At the outset, the valve armature is in its first end position X1. The current I_M assumes the value 0 and the voltage U_M across the valve assumes a first value U1. At a preset instant T1, the drive control device 120 closes the switch 110. This has the consequence that the voltage assumes a second value U2. This value lies in the range of the battery voltage Ubat. At the same time, the current I_M rises as a function of time. The armature of the valve at first shows no reaction.

This state is maintained until the current through the valve reaches a preset threshold value, which is in the range of about 10 amps. When this threshold value is reached, the current regulator 130 produces a corresponding signal and conducts this to the drive control device 120. The device 120 drives the switch 110 so that it opens again. This, in turn, causes a decay of the current flowing through the valve. The current regulator 130 compares the current value detected by the sensor 145 with a preset threshold value and, in dependence on the comparison result, produces a signal for action on the drive control device 120.

The device 120 sets the current or the voltage to the target value through opening and closing of the switch 110. This target value is about 10 amps in this example. The armature moves in

direction towards its second end position X2 from the instant at which the threshold value is reached and the current regulation is active.

A time window, which is defined by a lower limit T2 and an upper limit T3 and within which the switching instant T_{BIP} is expected to occur, is preset. It is particularly advantageous if the limits T2 and T3 of the time window are read out from a characteristic value field in dependence on engine operating parameters, for example, engine rotational speed, injected quantity of fuel and other such magnitudes.

Usually, a transfer is made from current regulation to voltage regulation from the instant T2 onward. This means that the voltage regulator 130 sets the voltage across the valve to a presettable voltage value in the order of magnitude of about 4 to 9 volts. The current now no longer fluctuates to and fro between two threshold values, but decays slowly. In that case, the armature continues its movement in direction towards its new end position X2. It is not necessary that the current decays slowly. If so desired, the current can have a steady, differentiatable course either side of the instant T_{BIP}.

During the movement of the valve armature, a voltage is induced in the coil of the electromagnetic load. At the switching instant T_{BIP}, the armature reaches its new end position and the movement stops. This has the effect that the induced voltage disappears which in turn has the consequence that the current I_M flowing through the coil has a different slope. This change in the

current course is detected by means of the evaluating device 140. At the end of the time window at the instant T3, a return can be made to current regulation or the switch 110 can be opened if T3 is equal to T4. At the instant T4, the switch 110 is opened and the drive control of the valve is terminated.

Preferably, a transistor is used as the switch 110. In that case, the loss power stressing of the switch 110 is very high during the voltage regulation. A reduction of this loss power is desirable for an increase in the general efficiency of the fuel injection system as well as for a reduction in thermal loading of the switch 110.

Accordingly, whilst the switch 110 is open, the freewheel device 150 is active. As a result, a current flows through the load 100 by way of the diode 150 as well as the sensor 145 whilst the switch 110 is open. Under ideal conditions, this means that the ohmic resistance of the electromagnetic load 100 as well as the voltage across from the diode 150 are 0 and the armature does not move, thus the current continues to flow unchanged. Under real conditions, however, the ohmic resistance of the load is not equal to 0 and a voltage in the order of magnitude of about one volt decays at the diode. The current course has a negative slope which experiences an additional reduction under the influence of movement or, more precisely, of the negative induced voltage.

When the armature of the load reaches its new end position X2, the induced voltage disappears. This has the consequence that the current decays more slowly or even rises. This change in the slope of the current course can be drawn upon for recognition of the switching instant T_{BIP}.

These conditions are illustrated in Fig. 2b. Up to the instant T2 and onward from the instant T3, the signal courses correspond to those of Fig. 2a. However, in the example of Fig. 2b, the switch 110 is opened at the instant T2. This has the effect that the current I_M through the valve decays as a function of time. When the armature reaches its new end position X2, the current decays with a smaller slope. The evaluating device 140 recognises this discontinuity or this change in the first derivative of the current course.

The method exemplifying the invention is explained in detail by reference to the flow diagram of Fig. 3. In a first step 300, a time window, which is defined by the instants T2 and T3 and within which the switching instant usually occurs, is preset in dependence on different operating parameters during the first phase of the drive control between the instant T1 and the instant T2.

Subsequently, a time counter is increased in a step 310. Current regulation takes place as long as the time counter has not exceeded the lower limit T2 of the time window. When it is recognised in an interrogation step 320 that the time counter has reached the lower limit T2, the switch 110 is driven in a step 330 so that it opens. Subsequently, the evaluating device 140 is activated in a step 340 so that it recognises the switching instant T_{BIP}. In a step 350, the evaluating device 140 ascertains the switching instant.

This means that the switching instant is ascertained within a time window in which the voltage decaying across the load is almost constant.

When it is recognised in an interrogation 360 that the time counter has exceeded the second threshold T3 of the time window, a normal current regulation is instituted in a step 370. As long as the time counter has not exceeded the second threshold, the time counter is increased in a step 380 and the interrogation step 360 is repeated.

It is also possible to return to current regulation as soon as a switching instant has been recognised.

Thus, current regulation is dispensed with and the switch 110 is opened during the time window within which the switching instant T_{BIP} is expected to occur. During this phase, the switching instant recognition takes place through evaluation of the current course. The evaluation of the switching instant can be by way of suitable known means.

The procedure of recognising the switching instant in the phase in which the freewheel circuit is active offers the advantage that no voltage regulation is required. This appreciably reduces the expenditure on components. The loss power stressing of the switch 110 during the time window is significantly reduced. The particular current course that is created offers the possibility of reliable and certain evaluation and thereby switching instant recognition for different types of electromagnetic valves with greatly different electrical and mechanical parameters. A current level falling under ideal conditions during the time window enables a more rapid reversal of the direction of movement of the armature by virtue of the low stored energy of the magnetic circuit during the switching-off of the valve, which is particularly advantageous with a view to short injection intervals.

CLAIMS

1. A method of determining a control parameter for an electromagnetic device incorporating a movable element, the method comprising the step of ascertaining a switching instant at which the movable element reaches an end position during movement thereof by detection of a discontinuity in the temporal course of a magnitude corresponding to the current through the electromagnetic device, the step of ascertaining being carried out during a freewheel phase.

2. A method as claimed in claim 1, comprising step of predetermining a time window within which the switching instant is expected to lie.

3. A method as claimed in claim 2, wherein the time window is predetermined in dependence on operating parameters.

4. A method as claimed in claim 2 or claim 3, comprising the step of activating a freewheel circuit within the time window by opening switching means connected in series with the device.

5. A method as claimed in any one of the preceding claims, wherein the switching instant is recognised by a change in the slope of the course of the current.

6. A method as claimed in any one of the preceding claims, wherein the device is an electromagnetic valve of a fuel injection system for an internal combustion engine.

7. A method as claimed in claim 1 and substantially as hereinbefore described with reference to Figs. 1, 2b and 3 of the accompanying drawings.

8. Equipment for determining a control parameter for an electromagnetic device incorporating a movable element, comprising means to ascertain, during a freewheel phase, a switching instant at which the movable element reaches an end position during movement thereof by detection of a discontinuity in the temporal course of a magnitude corresponding to the current through the electromagnetic device.

9. Equipment substantially as hereinbefore described with reference to Figs. 1, 2b and 3 of the accompanying drawings.

Patents Act 1977
Examiner's report to the Comptroller under Section 17
(The Search report)

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Application number
GB 9413277.6

Relevant Technical Fields

(i) UK Cl (Ed.M) G1N (NACNR,NACNS,NAEB,NCTA); G3N (NG2,NG4); H1P (PC); H2H (HEM); H3P (PCCL, PDSR)

(ii) Int Cl (Ed.5) F01L 9/04; F02D 41/20, 41/30; H01F 7/18; H01H 47/32

Databases (see below)
(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii) ONLINE DATABASES: WPI

Search Examiner
M G CLARKE

Date of completion of Search
14 SEPTEMBER 1994

Documents considered relevant following a search in respect of Claims :-
1 to 9

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
A	GB 2224156 A	(GENT LTD) see especially page 4 lines 1-29	
A	EP 0408963 A2	(FEV MOTORENTECHNIK GmbH) see especially column 3 lines 3-48	
A	US 4930040	(ASS TO WABCO WESTINGHOUSE) whole document	
A	US 4823825	(J BUCHL) whole document	
A	US 4653447	(ASS TO ROBERT BOSCH GmbH) whole document (acknowledged in the present specification)	

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